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RESEARCH USING THE COBE SATELLITE

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ABSTRACT/SUMMARY: We have been using the COBE Satellite to do research in cosmology. In particular we have probed the large scale structure and evolution of the universe. We have been using the COBE satellite data on the cosmic microwave and other backgrounds, processing and analyzing that data for the information that it can provide on the geometry and evolution of the universe as well as the energy and matter distribution in the early universe. Observations were discontinued at the beginning of 1994; however, data processing has continued, with this and secondary goals in mind and continuing with the detailed science data analysis and publications.

INTRODUCTION

The Cosmic Background Explorer (COBE) was launched 18 November 1989 after many years of preparation. It worked quite successfully for four years since that time taking high quality data. We have been participating in the development of the satellite mission, data processing, and analysis.

DESCRIPTION OF COBE

The Cosmic Background Explorer (COBE) project is producing maps of the sky at many different wavelengths (from 1 micron to 1 cm) using three instruments and addressing three primary questions. The instruments are the Differential Microwave Radiometers (DMR), the Diffuse Infrared Background Experiment (DIRBE), and the Far Infrared Absolute Spectrophotometer (FIRAS). Three major questions are:

(1) Is the cosmic background radiation equally bright in all directions? Different parts of the sky are expected to have different brightness because the Big Bang must have had density fluctuations that were the precursors of galaxies. We currently know that one half of the sky is about 0.1% brighter than the other half, but we think this difference is caused by the motion of the Earth through the radiation. The Differential Microwave Radiometers (DMR) are designed to look for this and other differences as the anisotropy experiment. After the processing and partial analysis of the first year's data, we believe that we have found the first evidence for those density fluctuations.

(2) Does the cosmic microwave background radiation have the predicted spectrum (intensity at each wavelength)? A discrepancy could exist if other energy sources besides isotropic expansion were effective in the early universe. The Far Infrared Absolute Spectrometer will compare the observed spectrum of the cosmic background radiation to the predictions with high resolution.

(3) Can we detect the accumulated light from the first stars and galaxies or other processes in the medieval universe? There are several infrared wavelengths at which we may be able to detect a faint uniform glow from the first stars and galaxies, depending upon when they were formed and how bright they were. The detection has not been possible previously, because the earth's atmosphere interferes with measurements and because the dust in the solar system and the galaxy confuses the analysis. The Diffuse Infrared Background Experiment (DIRBE) will search for this light. It will also measure the emissions of the solar system and the galaxy to approximately the 1% level over its operating bandwidth.

Secondary objectives are a study of galactic emission and structure and of more local sources of celestial emission. These include modeling galactic electron (synchrotron and HII) emission and interstellar dust as well as molecular emissions. Likewise interplanetary dust and the various planets and the moon are of interest.

General Concepts:

The Differential Microwave Radiometer (DMR) instrument is designed to look for very small level anisotropy in the cosmic microwave background radiation. The DMR all-sky maps show anisotropies at the level of a few parts per million to a few parts per 100,000. The signal-to-noise ratio with one year of data are not very

good. The best way to improve the signal-to-noise is taking new data. The instrument is now in its fourth year of observation. The second year data have been processed with a second generation of software and processing is beginning for the third year. Significant improvement in the quality of the data can only be obtained by either much longer observing times or a new mission with improved technology.

Another approach is more careful testing, data processing, and analysis techniques of the DMR data. The main thrust of the current effort is the more careful understanding and processing of the DMR data. The primary techniques are:

- detailed study of the instrument and software performance
- careful systematic error analysis and tests
- comparison of data processing techniques
- improved and increased data analysis procedures
- Monte Carlo simulation of the experiment and cosmological models

The goals of this effort are to remove the instrument signature as completely as feasible and to provide clean data for analysis and study to ourselves and the outside community. The data are validated by the DMR team. The current plan calls for delivery to the community of the full four year data sets in the fall of 1995. The first year data set was delivered in June 1993 and the two year data set in the summer of 1994. The other effort is to analyze these data sets and present the results of fitting and cosmological tests to the community and public as quickly as feasible. This has included fits to the dipole and quadrupole, two-point correlation functions, power spectra, information on the galactic emission, and possible extragalactic sources and comparison with various cosmological models. The primary emphasis is on basic results that are a step or two above the maps - e.g. the correlation function and power spectra. These are things that are of wide use to the cosmological community and are not deeply entwined with one particular theory but are close to the basic observation. These also relate to the team's deeper understanding of the original instrument and data. For example, we know that the cross-correlation is accurate to about the 10% level in terms of systematic effects such as the correlation of errors caused by the uneven sky coverage. At this stage we are trying to quantify and improve our corrections, limits, and understanding of these points.

Work Accomplished in 1994:

The past year was a very successful one for the DMR in the aftermath of the detection by the COBE DMR of cosmic background temperature anisotropies. The DMR team has continued data processing, analysis, and delivery of the first year data products, as well as publishing and preparing several papers. The primary people from Berkeley working on the DMR have been:

Jon Aymon	- half time
Giovanni De Amici	- quarter time
Jeanette Larsen	- half time as adminstrative assistant
Charley Lineweaver	- graduate student - 3/4th time
George Smoot	- half time
Luis Tenorio	- half time as post doc

Each has made significant contributions to the COBE DMR effort over the past year and is summarized in the following sections:

1994 Work by Jon Aymon

Jon Aymon's primary accomplishments are:

o DCP4. Delivered DMR pixel-perm facility, with DCP4, DRF4, and DPS4 using same DESCRIP.MMS, to become a single facility.

o DRF4. Delivered DMR geosynchronous pixel-perm facility, as above.

o DTO4. Validated this facility through proofreading, through test runs, and through original IDL procedures made to verify tracking of celestial objects reported in DTO4 flagging in test of PASS3 version.

o DPS4. Delivered DMR pixel-perm statistics facility (Ftest), as above. Have found IMSL routine yielding same results for Ftest as Numerical Recipes code used heretofore. Trying to run the IMSL code to get same results in shorter time; IMSL code very cpu-hungry as it stands.

o Developed IDL procedures to display DMR and other data for comparison,conferences, and papers. Assisted in generating IDL procedures for extragalactic point source work and display.

o Galaxy. Modified this program (for making galactic background maps) to generate dust component from FIRAS and DIRBE data. Work on Rhodes 2300MHz survey including software to pixelize data from FITS file and comparison with DMR galactic synchrotron model.

In addition Jon provided programming assistance to physicists and graduate students as requested as well as general emergency and miscellaneous programming and related tasks as needed.

1994 Work by Giovanni De Amici

Giovanni De Amici had a reduced COBE effort in 1994. Giovanni

o collaborated on the dipole paper Al Kogut et al.

o worked and exchanged ideas with Pete Jackson on the Moon model and its relevance for instrument performance evaluation

o ran long term plots looking for trends and correlations, and discussed with Jairo Santana their meaning (or lack thereof) and for instrument evaluation and for the eventual instrument performance paper.

o cleared up the algorithms for skewness and kurtosis for Jon Aymon and Pete Jackson.

o revised the draft of the DMR On-orbit Instrument Performance paper and circulated it to the team members most likely to be involved.

o presented lectures on COBE results at the Universities Milano and Bologna San Francisco State, Cal State Sonoma and a popular lecture on COBE's cosmology at White Mountain Research Station and Berkeley.

o coordinated the Berkeley effort for low-frequency measurements and gathering of galactic emission data for future better galactic modeling of the galactic foreground.

1994 Work by Jeanette Larsen

Jeanette has worked as an admistrative assistant spending a part of her time tracking COBE expenses, travel, and manuscripts / papers.

1994 Work by Charley Lineweaver

Charley Lineweaver's publications and reports:

- o His PhD thesis ``Correlation Function Analysis of the COBE DMR Skymaps"
- o Lineweaver et al ``Correlated Noise in the COBE DMR Skymaps" APJ 436 in press (Dec 1 1994)
- o Lineweaver et al ``The Cosmic Microwave Background Dipole Anisotropy: Testing the Standard Model" Astrophys. Lett. and Comm., in press

- o Charley is a coauthor of:
  Banday etal 1994 RMS at 7 and 10 degrees
  Bennett etal 1994 Two Year Results Paper
  Hinshaw etal 1994 Limits on Three-Point Correlations in the COBE DMR First Year Anisotropy Maps
  Wright etal 1994 Comments on the Statistical Analysis of Excess Variance in the COBE DMR Maps

- o Lineweaver et al 1995 "Comparison of the COBE DMR and Tenerife Data"

Charley worked with George Smoot getting information from Tenerife collaboration members Steven Hancock and Anthony Lasenby to produce a 21 page report: ``An Investigation of Structure Common to the COBE DMR and Tenerife data" presented to the SWG. Charley then rewrote this report to include SWG comments. The SWG did not feel that the results were strong enough to warrant publication at the time. The quality of the comparison has improved through the addition of more Tenerife data and the two-year DMR maps so that a new comparison has been undertaken. A draft paper of comparison mentioned in the first line has being circulated to the DMR team and submitted for publication.

- o Charley upgraded Monte Carlo routines to simulate arbitrary spectral index n skies. These simulation abilities are used to produce n and Qrms distributions which verify the reported values for n and Qrms-ps.

- o Charley collaborated with coworkers and will be coauthor on papers now in progress as well as those for the future.

1994 Work by George Smoot

George Smoot wrote, published, or coauthored last year:

Banday et al 1994 RMS at 7 and 10 degrees
Bennett et al 1994 Two Year Results Paper
Gorski et al. 1994. On determining the spectrum of Primordial inhomogeneity from the COBE DMR sky Maps
Hinshaw et al 1994 Limits on Three-Point Correlations in the COBE DMR First Year Anisotropy Maps
Kogut et al 1994 Search for Unresolved Point Sources in the COBE DMR Two year Sky Maps
Kogut et al 1994 Peak Correlation Function and Gaussian Statistics
Lineweaver et al 1994 ``Correlated Noise in the COBE DMR Skymaps'' APJ 436 in press (Dec 1 1994)
Lineweaver et al 1994 ``The Cosmic Microwave Background Dipole Anisotropy: Testing the Standard Model'' Astrophys. Lett. and Comm., in press
Smoot et al 1994 Statistics and Topology of DMR First Year Maps
Wright et al 1994 Comments on the Statistical Analysis of Excess Variance in the COBE DMR Maps
Wright et al 1994 Power Spectrum from the DMR two-year Sky Maps.

George Smoot has given several scientific and public lectures. Some of the scientific lectures will be published as conference or workshop proceedings.

Work is in progress on drafts of the papers about the polarization of the CMB, significance of the signal in the DMR maps, the power spectrum, comparison to other experiments, and comparison to various models

George Smoot's particular intellectual contributions to the COBE team effort include:

o the paper writing and publishing discussed above.

o the encouragement and development of various DMR team members such as Charley Lineweaver and Luis Tenorio

o work on data processing schemes such as baseline removal and magnetic susceptibility

o work on making and interpreting DMR polarization maps

o PI role including DMR and COBE meetings

o work with Banday, Kogut, and Tenorio on CMB and map fluctuations statistics

o work with Gorski and Wright on power spectrum estimation

o work with Charley Lineweaver on correlation of errors in map and covariance matrix for the correlation function.

o work on topological measures of the data with Tenorio and Kogut

o work on collapsed 3-point (and higher) correlation functions with Kogut and Hinshaw

o work on validating the MIT x DMR cross-correlation and Tenerife comparison

o work on the issue of cold dust as a possible foreground

o work on estimating extragalactic source contributions

The people working at Berkeley are listed earlier in the proposal. George Smoot has made it a point to spend time at the CDAC and GSFC through out the year working with members of the DMR team.

1994 Work by Luis Tenorio

Luis Tenrio's accomplishments:

o Supported and maintained DEV4 code

o Checked the DEV4 results for every new pass of the data

o Developed code for the search of axial and planar symmetries

o Developed code to study DMR polarization maps

o Developed code for statistics and genus simulations

o Developed concepts and algorithms for ``New Methods for Inference from COBE Data'' which provides a new way to get a power spectrum from the DMR data.

o Work on papers to be drafted, written, and published

Co-authorship or authorship in:

Wright, E., et al, ``Comments on the Statistical Analysis of Excess Variance in the COBE DMR Maps''. Ap.j.

Tenorio, L., et al, ``Comments on the COBE DMR Quadrupole Estimation''. Proceedings of Santander Conference

Smoot, G., et al, ``Statistics and Topology of the COBE DMR First Year Maps''. Ap.J.

Lineweaver, C., et al, ``The Cosmic Microwave Background Dipole Anisotropy Testing the Standard Model'', Astrophysical Letters and Communications.

Lineweaver, C., et al, ``Correlated Errors in the COBE DMR Sky Maps''. Ap.J.

Banday, A., et al, ``On the RMS Anisotropy at 7 and 10 Observed in the COBE-DMR Two Year Maps''., Ap.J. Lett.

SUMMARY

1994 followed previous years as a very active and productive year following the leads and work initiated by the first year's data analysis and discovery of CMB fluctuations. We anticipate that the rest of the year and the next year will continue along at this high level as finally 4th year of data are processed and analyzed.